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INTERFEROMETRIC OBSERVATIONS OF SOLAR FLARE PRECURSORS AT 10.6 GHz

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The purpose of this study was to examine a data base of interferometric solar microwave data in order to identify, evaluate and interpret preflare microwave signatures, with reference to their possible role for the short-term prediction of solar flares. The data base used was acquired by the Owens Valley solar interferometer at 10.6 GHz between February 19, 1980 and March 31, 1981. Twenty-seven major flares which occurred between February 19 and August 31, 1980 and for which good quality interferometric

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data were available, were selected using optical, soft x-ray OR microwave flux criteria. These events were analysed in detail; very similar preflare signatures noted in four (15%) of the cases. Other unusual preflare behavior was noted in four additional cases. The most common signature was a step-like increase in signal amplitude, accompanied by a decrease or reversal in the degree of polarization. Such a signature occurred between a few minutes to a few tens of minutes before the start of the impulsive phase. Optical data, available in three cases, showed the microwave changes were simultaneous with either small brightenings or small-scale filament disruptions.

Physically, this precursive signature may be identified with the onset phase of solar flares, when slow heating in the metastable magnetic loops destabilize the system, leading to rapid energy release in the impulsive phase. The reason for the distinctive polarization signature is not understood at present, but may be related to the site of the heating within the magnetic loops.

This signature was quantified in terms of a computer program, ONSET, which was used to review the second half of the data base. It succeeded in 'predicting' a comparable percentage (5 out of 54) of major flares observed between September 1, 1980 and March 31, 1981. The false alarm rate was evaluated using the first half of the data base and was found to average 3 per week. The false alarms can be attributed to four sources: (1) Signal variations caused by the effect of the earth's rotation on the interferometer's response to spatially complex active regions. (2) Predictions which led to smaller flares than the major flare identified using the adopted criteria. (3) The crudeness of the adopted algorithm. (4) Real fluctuations in the solar radio emission which did not lead to flares. The false alarm rate was sufficiently low to eliminate random coincidences as a factor. It was far too high, however, to make single-frequency interferometric polarimetry a practical stand-alone tool for short term flare prediciton, except in the most false-alarm tolerant situations.

If gyroresonance opacity plays a significant role in the microwave emission at 10.6 GHz during the onset phase, then it would be expected that multiple-frequency interferometry would be able to significantly reduce the false alarm rate as well as increase the fraction of flares with distinctive preflare microwave signatures.

INTERFEROMETRIC OBSERVATIONS OF SOLAR FLARE PRECURSORS AT 10.6 GHZ

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ABSTRACT

The purpose of this study was to examine a data base of interferometric solar microwave data in order to identify, evaluate and interpret preflare microwave signatures, with reference to their possible role for the short-term prediction of solar flares. The data base used was acquired by the Owens Valley solar interferometer at 10.6 GHz between February 19, 1980 and March 31, 1981. Twenty-seven major flares which occurred between February 19 and August 31, 1980 and for which good quality interferometric data were available, were selected using optical, soft x-ray OR microwave flux criteria. These events were analysed in detail; very similar preflare signatures noted in four (15%) of the cases. Other unusual preflare behavior was noted in four additional cases. The most common signature was a step-like increase in signal amplitude, accompanied by a decrease or reversal in the degree of polarization. Such a signature occurred between a few minutes to a few tens of minutes before the start of the impulsive phase. Optical data, available in three cases, showed the microwave changes were simultaneous with either small brightenings or small-scale filament disruptions.

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If gyroresonance opacity plays a significant role in the microwave emission at 10.6 GHz during the onset phase, then it would be expected that multiple-frequency interferometry would be able to significantly reduce the false alarm rate as well as increase the fraction of flares with distinctive preflare microwave signatures.

I. INTRODUCTION

The purpose of this study was to examine a moderate size data base of interferometric solar microwave data in order to identify, evaluate and interpret preflare microwave signatures with reference to their possible role for the short-term prediction of solar flares. In terms of Martin's (1980) terminology, this study is dealing with "distinct" preflare events -- that is, events which are characterized by irreversible, continuous changes culminating in the occurrence of a flare, as opposed to evolutionary or statistical association of active region characteristics with the general level of solar activity. In this context, we define preflare events as those events occurring before the start of the impulsive phase.

II. MICROWAVE OBSERVATIONS

The study is based on observations obtained with the Owens Valley Solar Interferometer (Zirin, Hurford and Marsh 1978) which obtained solar observations at 10.6 GHz up to 8 hours per day almost daily from February 19, 1980 until March 31, 1981. The instrumentation consisted of a pair of 27-m fully-steerable parabolic antennas (half power beam width of 4.4 arc-min at 10.6 GHz) deployed on either a 700-foot east-west baseline (until June 29, 1980) or a 450 foot northwest to southeast baseline. The fringe spacing on the sun varied between 0.5 and 2 arc-minutes, depending on date and time of day. Occasionally, a 40-m antenna was added to

the system to enable 3-element interferometry with fringe spacing as short as 4.6 arc-seconds.

The original data was acquired with 50 msec time resolution (occasionally 25 or 100 msec), recorded and archived on magnetic tape. Appropriate time averaging was introduced during the data analysis. The system observed alternately in left and right circular polarization, with all active signal processing paths common to both polarizations. Therefore, the system sensitivity to small polarization changes was exceptionally good.

The normal observing routine consisted of brief observations of a cosmic source (for amplitude and phase calibration) alternating with 60 to 90 minute observations of an active region. The choice of active region was generally based on the Solar Maximum Mission observing program or a region likely to produce flares, as determined by optical evaluation at Big Bear Solar Observatory.

The overall methodology of the study was to identify a set of major flares for which we had interferometric observations both of the impulsive phase and of the preflare situation. The preflare microwave activity was then examined in detail to identify any potentially unusual behavior; that is, changes in any aspect of the microwave signal that could not be attributed to the normal change in amplitude, phase or apparent degree of polarization due to the rotation of the earth and consequent change in the

fringe spacing or orientation. (As discussed by Kundu and Alissandrakis(1975), such effects can cause a stable source to display a variable interferometric signature.) Changes attributable to instrumental effects, such as pointing, tracking or atmospheric effects were also disregarded. The sensitivity of the system to preflare changes varied markedly from event to event. In some cases, where the active region structure was simple, a very stable interferometric response was observed and relatively subtle preflare signatures would have been readily apparent. In other cases, the interferometric output varied significantly through much of the day, due to a more complex distribution of microwave sources within the field of view and/or frequent (but minor) flaring activity. In such cases, only relatively gross preflare signatures changes could be identified.

The criterion chosen to define major flares for this purpose was that a flare had to have either optical importance 1 or greater, soft X-ray class M1 or greater, or 10.6 GHz flux density of 50 sfu or greater. Such a criterion was adopted so that an adequate number of events would be available for careful study and so that no preference would be given to one type of flare over another. The time period examined at this stage was limited to Feb 19, 1980 to August 31, 1980, thus leaving a comparable period (September 1, 1980 to March 31, 1981) available for a subsequent test of any preflare signatures identified.

Initially, an overcomplete list of 46 flares was identified as possibly meeting such criteria. These events were then studied in detail and, in some cases, deleted from further study on the basis of data quality, inadequate preflare coverage, etc. The presence or absence of preflare activity was not a consideration in such rejection. The final list of 27 'major' flares occurring in this time period and for which satisfactory OVRO data was available is shown in Table 1. The data for these flares was reduced and plotted, first with 10-second averages in Stokes R and L, on logarithmic scales. Such plots effectively display small variations in circular polarization, since the linear separation of the amplitudes corresponds to the degree of polarization. Additional displays, optimized for each event, were generated as needed and examined in detail. Since the purpose of this work was to identify distinct preflare events rather than those of a more evolutionary character, each day was analyzed independently, and no formal attempt was made to compare the interferometric signatures from day to day.

Examination of the preflare microwave data for the 27 major flares identified in Table 1 showed very similar preflare microwave signatures in four cases, with other microwave changes in four others. Optical data from Big Bear Solar Observatory was also examined and will be referred to below.

III. DISCUSSION OF INDIVIDUAL EVENTS

In this section we will discuss the preflare microwave behavior for the eight events that showed some type of preflare changes not attributable to the instrumental causes.

A/ March 23, 1980.

The beginning of the impulsive phase of this event at 1655 was preceeded by a pair of step-like increases in the left circularly polarized (LCP) signal at 1648 and 1651, accompanied by smaller increases in the right circularly polarized (RCP) amplitude (Figure 1). The result was that the polarization had reversed from RCP to LCP four minutes before the impulsive phase began, and that the overall amplitude in Stokes I more than doubled. Optically, the first step coincided with the lifting off of one leg of a Y-shaped filament (Figure 2). The second step coincided with the disintegration of the other leg, leaving only the base. The impulsive phase began about 4 minutes later. The impulsive and decay phases of this microwave event are discussed in detail elsewhere (Marsh et al., 1981).

B/ May 15, 1980.

The M2 event at 2047 (Figure 3) was preceeded in this case by evolution of the active region polarization beginning at about 1935. This was qualitatively similar to the preceeding case, except on a much slower time-scale.

Note the dramatic reduction and reversal in the sense of polarization starting at 1935, which followed a relatively stable morning. It is important to note that the sun was at the local meridian at about this time. With the stable meridian fringe spacing associated with an east-west baseline at the local meridian, it is therefore very unlikely that the polarization change that occurred following 1935 represented anything other than a real temporal change in the source. Note also the return of the polarization to its preflare state following the event.

C/ June 19, 1980.

The event at 1839, shown in Figure 4, was clearly preceeded by a steplike increase at 1832, with some reduction in degree of polarization. Amplitudes before and after this event were very stable. Optical data, shown in Figure 5, show that this step was associated with a continuing development of a small optical brightening.

D/ July 1, 1980.

This X2 event was indeed a major flare featuring not only gamma-ray and white-light emission, but also magnetic transients (Zirin and Neidig,1981; Zirin and Tanaka, 1981). The impulsive phase of this event began at 1626 UT, early in the day at OVRO, but after a significant decrease in polarization at 1619 with the same character as the events discussed above. This preflare microwave signature coincided with optical brightening in a well defined compact

loop as shown in Figure 7.

E/ July 12, 1980

The two events on July 12, 1980 (Figure 8) each showed a striking decrease in their signal amplitudes, accompanied by a decrease in polarization. In noting the contrast to the previous cases, it should be recalled that the presence of a new microwave source in the field of view of an interferometer can result in a decrease in the resulting amplitude. (This occurs because the contributing sources add vectorially, not as scalars, in determining the final amplitudes.) Thus, it is possible that the decrease was due to the addition of a new source. Optically, there was almost continual low level activity during this time.

F/ April 11, 1980

The event at 2312 on April 11 occurred on an otherwise-quiet day which featured a relatively stable microwave profile until a small event occurred at 2259 UT(Figure 9). The feature of note, however, is not the occurrence of this event, but rather the failure of the microwave profile to return to its previous level after this event was over. Instead, it remained at a stable, enhanced level until the major flare began at 2310. Note also the reversal in polarization between 2336 and 2348.

G/ May 16, 1980.

The impulsive flares at 2205 and 2210 (Figure 10) occurred in AR2456 and left the active region amplitudes in an enhanced, stable state. The major flare in terms of soft x-rays occurred at 2232 following this enhancement. In this case the correlation may be deceptive, however, for optically the event at 2232 occurred in what appeared to be a magnetically separate part of the active region. Furthermore, close examination of Figure 10 shows that the preflare enhancement remained after the event at 2232. The decrease at 2240 is a remarkable case, discussed elsewhere (Hurford and Tang 1981), in which a surge, originating in the event at 2232, occulted the compact source of emission of the active region.

IV. PRE-FLARE MICROWAVE SIGNATURE

Four of the cases discussed above display a common characteristic. A few minutes or tens of minutes before a major flare, a step-like increase in fringe amplitude occurs, accompanied by a decrease or reversal in the degree of polarization. It then remains at an enhanced state until the occurrence of the major flare. In some cases, the increases were accompanied by small brightenings in H-alpha, brightenings which otherwise might not be exceptional.

To objectively evaluate the significance of this preflare behavior and its potential usefulness for real-time short-term flare prediction, the signature was quantified into a computer-compatible form which could then be applied to a real-time data stream.

The algorithm adopted can be formally stated in the following procedure.

1. Calculate 30-second averages of amplitude in right and left circular polarization.

2. Calculate their sum and difference, I = R + L, V = R - L, and the degree of polarization, P = V / I. (Note that this definition of I and V is slightly non-standard in that the phases are not taken into account.)

3. Verify that the following stability requirements are met: a. The value of I should not differ from either of the previous two values of I by more than 20%. b. The value of V should not differ from either of the previous two values of V by more than 20% of I. The purpose of this requirement was to eliminate many flare-associated changes.

4. Compare the 'new' sample with each 'old' sample acquired over the previous 30 minutes as follows: a. Does the value of I in the new sample represent an increase of 50% or more over the value of I in the old sample? b. Does the value of V in the new sample represent a decrease of 50% of more or a reversal in sign compared to the old sample?

c. Was |P| in the old sample at least 10%?

5. If the answer to all three questions is YES for any single old sample, then a positive 'prediction' of an imminent solar flare is issued.

The foregoing algorithm represents an attempt to define an objective algorithm which could be applied to a real-time data stream. In practice, its application to the data was modified in two minor respects. In cases where inspection of the existing data displays clearly and unamibiguously showed that the criteria would or would not be satisfied, this state was accepted without confirmation by ONSET. Cases with any potential ambiguity were analysed by ONSET. The second modification was that in cases where the criteria were marginally satisfied, so that predictions were successively made and withdrawn as the signal fluctuated around the threshold, the resulting multiple predictions were counted as one prediction.

The algorithm was used to test the significance of the preflare signature by applying it to the second half of the data base (September 1, 1980 to March 31, 1981). Using the same criteria as defined above, 54 major flares were observed during this period. These are listed in Table 2. The same preflare signature was found in 5 of the 54, a fraction that is statistically consistent with expectations based on the first half of the data base. Figures 11 to 15 show the time profiles of these five events. Overall, the

signature was found in 11% (9 of 81) major flares observed over a 58 week period at the maximum of the solar cycle.

The false alarm rate of such a signature was determined by applying it to the entire first half of the data base, irrespective of the occurrence of major flares. The number of false 'predictions' varied significantly from month to month with an average of 3 per week. Such a false alarm rate is significant in two respects. First, noting an average duration of 15 minutes for each prediction and 40 hours per week of active region observations, this implies that the number of chance predictions of the 27 major flares occurring in this period is 0.5 compared to the 4 actually predicted. Thus, it is highly unlikely that the predictions were due to chance coincidences. Second, it is clear that such microwave data by itself could not serve as a practical flare alarm, except in false-alarm tolerant situations.

The causes of the false alarms are basically fourfold. 1. The most frequent cause was the effect of the earth's rotation on the interferometer's response to a spatially complex source. This arose because at any one time, an interferometer measures a specific Fourier component of the spatial distribution of the source. The specific Fourier component depends on the separation of the antennas (in units of wavelength), the orientation of the baseline joining the antennas and the location of the source in the sky. As the earth rotates, the interferometer therefore successively measures different Fourier components of the

source distribution so that stable sources can exhibit a time variable signal. In the algorithm above, the requirement that the comparison of 'old' and 'new' amplitudes be made over a time difference of less than 30 minutes eliminated most of such effects. The most common residual effect, termed a 'structural null' and illustrated in Figure 16, often exhibits significant polarization changes over a time scale of only a few minutes. Such structural nulls were a major source of false alarms.

2. In a number of occasions, predictions led to flares which did not qualify as 'major' under the criteria adopted above or the prediction occurred too late into a real flare to be significant.

3. The algorithm adopted above was crude in the sense that it could have been refined to eliminate several false alarms without seriously affecting its success rate. Such complications were not felt to be justified at this time.

4. There were some cases of apparently real solar variations satisfying the signature requirements which did not result in flaring activity.

V PHYSICAL SIGNIFICANCE OF THE PREFLARE MICROWAVE SIGNATURE

The impulsive or flash phase of solar flares represents the most rapid conversion of stored magnetic energy into energetic particles, thermal and mechanical energy. Thus for many processes (including those of solar-terrestrial

interest), it defines the 'start' of the flare. It has been known for some time, however, (cf. Svestka, 1976; Martin, 1980; van Hoven et al., 1980) that there sometimes is energy release on a much slower time-scale preceeding the beginning of the impulsive phase. This onset phase of flares has been observed as H-alpha brightenings, EUV and soft X-ray emission. We interpret the present results to show that the onset phase often has detectable microwave emission as well.

In retrospect, such microwave emission is not surprising. The preflare active region emits microwave emission through thermal bremsstrahlung (free-free) and the gyroresonance process. Thus depending on whether the source is optically thin (free-free) or thick (gyroresonance), its emission is sensitive to temperature, electron density and/or the magnetic field strength, so that any significant change in these quantities is likely to be reflected in the microwave emission. The intensity of these changes in microwave emission as found here (often just a few tenths of a solar flux unit) would often render them below or just at the thresholo of detectability of typical radio patrol systems. There are observable here because of the sensitivity of the interferometer to small-scale sources.

Physically, the most interesting feature of the onset phase microwave emission is the polarization. Since I increases and V decreases, the additional emission must have the opposite sense of polarization from that which dominates

the active region emission. Although the present work cannot definitively address this point, it does suggest that the sources (and, hence, the preheating of the active region plasma in the onset phase) may be occurring preferentially in the weaker, rather than the stronger magnetic field polarity.

VI CONCLUSIONS AND PROSPECTS

A distinctive signature, observable at 10.6 GHz with inteferometric polarimetry, has been found to occur a few minutes to tens of minutes before the beginning of the impulsive phase of 11% of major solar flares. Physically, this signature is identified with the onset phase of flare in which slow preheating of the active region plasma may lead to the rapid release of magnetic energy in the impulsive phase. Although the signature can be quantified so as to permit its automated identification in real-time, the false alarm rate of 3 per week seriously compromises its suitability for practical flare prediction.

It is possible that some of these limitations may be overcome by the use of multiple-frequency interferometry. In particular, it should be possible to significantly reduce the false alarm rate since the 'structural nulls' discussed in Section V above, and which provided most of the false alarms, can be readily distinguished from real solar changes when observed at more than one frequency (or with more than one baseline at a single frequency). With multiple-

frequency observations, they are expected to occur successively at different frequencies while real solar changes would occur simultaneously. Furthermore, if gyroresonance opacity is playing a significant role in the onset-phase microwave emission, then the polarization signature observed would be expected to be an intrinsically narrow band phenomenon, occurring in any one situation only over a limited frequency range (typically between the second and third harmonic of the local gyrofrequency). Thus, if the flare to flare variation of local gyrofrequency (i.e., magnetic field strength) varied over a factor of ~10 range, the polarization signature would be expected to be observable at a fixed frequency in only log(1.5) / log (10) or ~18% of the cases. Thus multiple frequency observations, expected to be available soon, might be expected to both observe such signatures in a higher fraction of flares, as well as have a significantly lower false alarm rate.

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TABLE 1 -- LIST OF 'MAJOR' FLARES WELL-OBSERVED BY OVRO
FEBRUARY 19,1980 - AUGUST 31, 1980

---DATE----	-UT-	OPTICAL	SOFT X-RAY	LOCATION	REGION
1980 FEB 20	2016	1B	C7	S08E28	AR228
1980 FEB 25	2005	1B		N10E90	
1980 MAR 23	1658	1B	C7	S28W49	AR2339
1980 APR 10	1925	1N		N19W36	
1980 APR 11	2312	1N	M1	N10W70	AR2372
1980 APR 30	2026	SN	M2	S13W90	AR2396
1980 MAY 01	1840	1B	C5	S24W61	AR2420
1980 MAY 02	2343	1N		N26E57	AR2423
1980 MAY 05	1932	1F	C3	S26E14	AR2418
1980 MAY 07	2048	SN	C3	S22W16	AR2418
1980 MAY 15	2047	1B	M2	S12E65	AR2456
1980 MAY 16	2233	1B	M2	S14E48	AR2456
1980 MAY 28	1952	1B	X1	S18W35	AR2470
1980 MAY 28	2207	1B	M3	S24W33	AR2470
1980 MAY 28	2344	1B	M7	S16W38	AR2470
1980 JUN 04	2301	1B	X2	S14W69	AR2478
1980 JUN 19	1839	1B	M1	S27E42	AR2522
1980 JUN 24	2003	1B	M1	S23W13	
1980 JUN 29	1824	2B	M4	S25W90	AR2522
1980 JUN 30	1828		M1		AR2544
1980 JUL 01	1628	1B	X2	S12W37	AR2544
1980 JUL 11	1904	2B	X1	S10E72	AR2562
1980 JUL 12	1737	SB	C7	S09E59	AR2562
1980 JUL 12	1828	1B	M2	S12E66	AR2562
1980 JUL 13	1719	SB	M2	S11E46	AR2562
1980 JUL 20	1927	1B	M1	S19W44	AR2562
1980 AUG 23	2129	1B	M2	N16W39	AR2629

TABLE 2 -- LIST OF 'MAJOR' FLARES OBSERVED BY OVRO
SEPTEMBER 1, 1980 - MARCH 31, 1981

---DATE----	-UT-	OPTICAL	SOFT X-RAY	LOCATION	REGION
1980 SEP 22	1619	1B	C3	N05W09	AR2691
1980 OCT 08	2034		M3		AR2725
1980 OCT 11	1748	1B	C7	S08E31	AR2725
1980 OCT 25	1843	1N	C3	S20W32	AR2744
1980 OCT 27	2203	1N	C4	S19W60	AR2744
1980 OCT 28	2226	1N	M1	S21W72	AR2744
1980 NOV 05	1641	1B	M2	N08E11	AR2776
1980 NOV 07	2231		M2		
1980 NOV 08	2007	1B	M1	S08E43	AR2779
1980 NOV 11	1725	1B	M1	S13E03	AR2779
1980 NOV 11	2054	1B	M3	S13W03	AR2779
1980 NOV 12	1702	1B	M1	S14W11	AR2779
1980 NOV 12	2243	1B	M3	S13W18	AR2779
1980 NOV 13	1744	SN	M1	S10W30	AR2779
1980 NOV 13	1924	2B	M4	S16W32	AR2779
1980 NOV 15	2007		M2		AR2779
1980 NOV 15	2114	1B	C8	S11W58	AR2779
1980 NOV 15	2148	1N	M1	S10W54	AR2779
1980 NOV 16	1742	1N	C4	S18W60	AR2779
1980 NOV 23	1755	1B	C2	N11W23	AR2793
1980 NOV 23	1845	SF	M2	N13W23	AR2793
1980 DEC 11	2225	SB	M1	N15E10	AR2826
1980 DEC 12	1703	1B	M2	N13E03	AR2826
1980 DEC 12	2113	SB	M1	N13W09	AR2826
1980 DEC 15	1840	1N	M1	N15E35	AR2841
1980 DEC 15	1927	2B	M5	N11E28	AR2840
1980 DEC 19	2014	1N	C5	N05W25	AR2840
1980 DEC 28	1908	SB	M1	S22W04	AR2855
1981 JAN 03	2202	1N	C1	S05W67	AR2857
1981 JAN 10	2057	1N	C2	S12W49	AR2874
1981 JAN 25	1647	SB	M2	S13E75	AR2911
1981 JAN 25	1911	SF	M1	S13E90	AR2911
1981 JAN 25	2249		M1		
1981 JAN 25	2349	SF	M1	S15E85	AR2911
1981 JAN 31	2401	1B		S14E06	AR2911
1981 FEB 02	1711	2B	M1	S08W04	AR2918
1981 FEB 15	1905		M1		AR2930
1981 FEB 17	1846	1N		N21W15	AR2941
1981 FEB 17	1913	1B	M1	N12W06	AR2947
1981 FEB 17	2150	2B	X1	N20W20	AR2941
1981 FEB 26	1953	3B	X4	S15E50	AR2958
1981 FEB 26	2333	1B	M1	S14E44	AR2958
1981 FEB 27	2309	SN	M1	S18E39	AR2958
1981 MAR 09	1853	1B	M1	N13E28	AR2971
1981 MAR 13	2101	1B	M1	N12W25	AR2971
1981 MAR 13	2330		M2		AR2971
1981 MAR 14	2348	1B	M1	N09W38	AR2971
1981 MAR 22	1950	1B	M1	N10W45	AR2984
1981 MAR 22	2353	2B	M8	N08W47	AR2984
1981 MAR 23	1737	1B	M1	N07W57	AR2984
1981 MAR 23	2118	1N	M1	N09W61	AR2984
1981 MAR 26	1815	SB	M1	N17W21	AR2993
1981 MAR 26	1940	1B	C5	N11W46	AR2993

FIGURE CAPTIONS

Figure 1. Microwave time profile for March 23, 1980 event. The top panel shows the amplitude in Stokes I on a linear scale. The center panel shows the RCP and LCP behavior on a logarithmic scale to illustrate the preimpulsive phase changes at 1648 and 1651. The dropout at 1702 is instrumental. The lower panel shows the phase behavior in RCP and LCP.

Figure 2. H-alpha observations of the March 23, 1980 event. Note the disappearance of the upper leg of the dark filament (left center) at between 1647 and 1648, (coincident with the first change in the microwave polarization in Figure 1) and the disintegration of the lower leg by 1650.

Figure 3. Microwave time profile for the May 15, 1980 event. The format is the same as Figure 1. Note the same polarization behavior as in Figure 1, but with a considerably slower time scale.

Figure 4. Microwave time profile for the June 19, 1980 event. The format is the same as Figure 1. The preimpulsive-phase step-like increase in amplitude and decrease in polarization is clear.

Figure 5. H-alpha observations for the June 19, 1980 event. The steplike increase in microwave amplitude at 1832 coincided with a continuing development of a small optical brightening.

Figure 6. Microwave time profile for the July 1, 1980 event. The format is the same as in Figure 1. Note the now-familiar polarization signature at around 1620.

Figure 7. H-alpha observations for the July 1, 1980 event. Note the intensification of the H-alpha brightness in the lower right bright loop at 1620.

Figure 8. Microwave time profiles for the two major flares on July 12, 1980. The format is the same as Figure 1. Note the amplitude decreases before the impulsive phase. (See text for a discussion of their possible significance.)

Figure 9. Microwave time profile leading up to the major flare at 2311 on April 11, 1980. The format is the same as

in Figure 1. Note the polarization reversal during the calibration gap at 2240 and the failure of the microwave amplitude to return to its previous level after the smaller event at 2259.

Figure 10. Microwave time profile leading up to the major flare at 2232 on May 16, 1980. The format is the same as in Figure 1. Note the failure of the microwave amplitude to return to its previous level after the smaller events (in soft X-rays) at 2205 and 2210.

Figure 11. Microwave time profile for the November 7, 1980 event.

Figure 12. Microwave time profile for the November 11, 1980 event.

Figure 13. Microwave time profile for the November 13, 1980 event.

Figure 14. Microwave time profile for the November 15, 1980 event.

Figure 15. Microwave time profile for the November 23, 1980 event.

Figure 16. Microwave profile of a typical structural null caused by the effect of the earth's rotation on the interferometer's response to a spatially complex source.

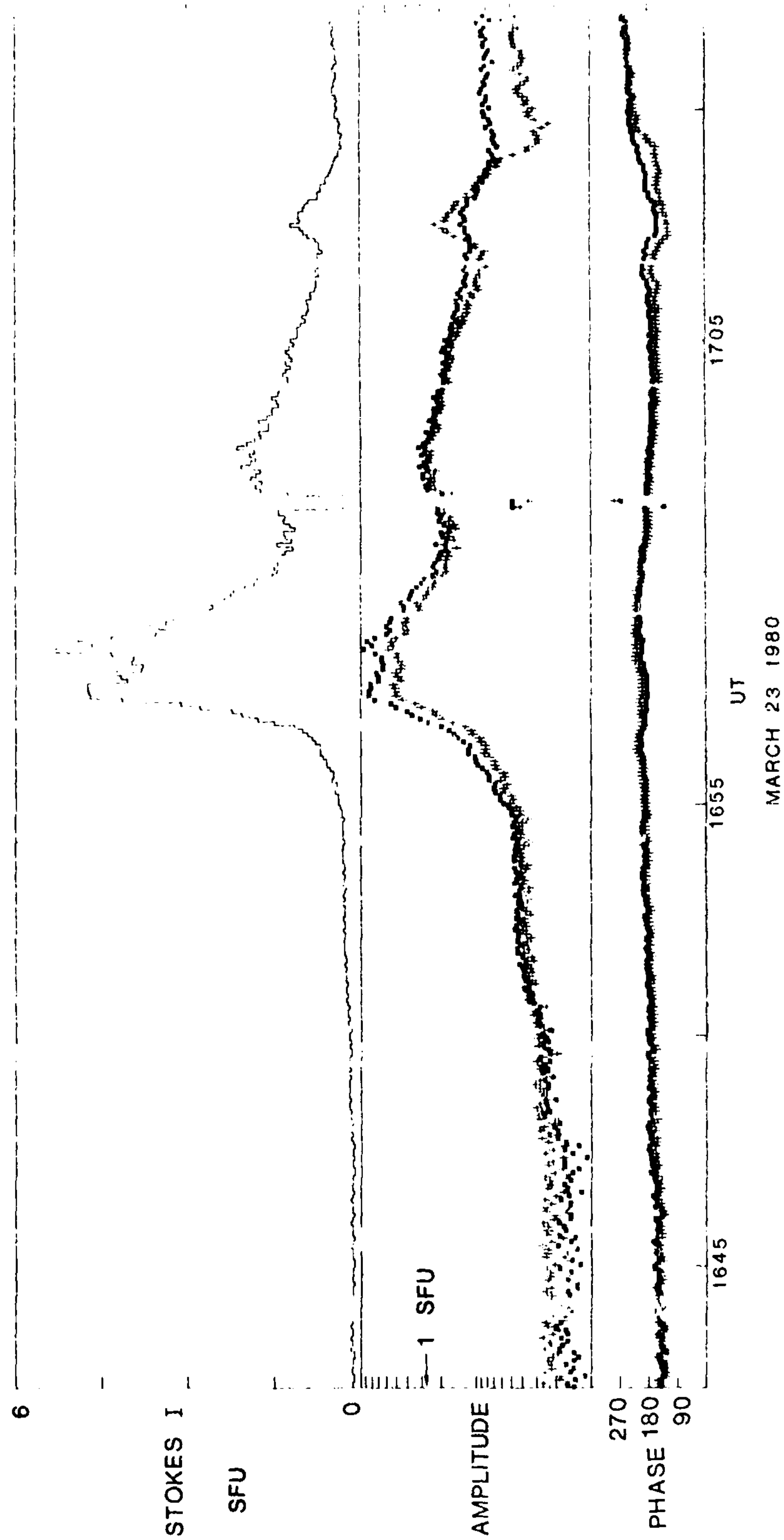

STOKES I
SFU
6
0
AMPLITUDE
1 SFU
PHASE
270
180
90
1645
1655
1705
UT
MARCH 23 1980

FIGURE 1

3-23-80

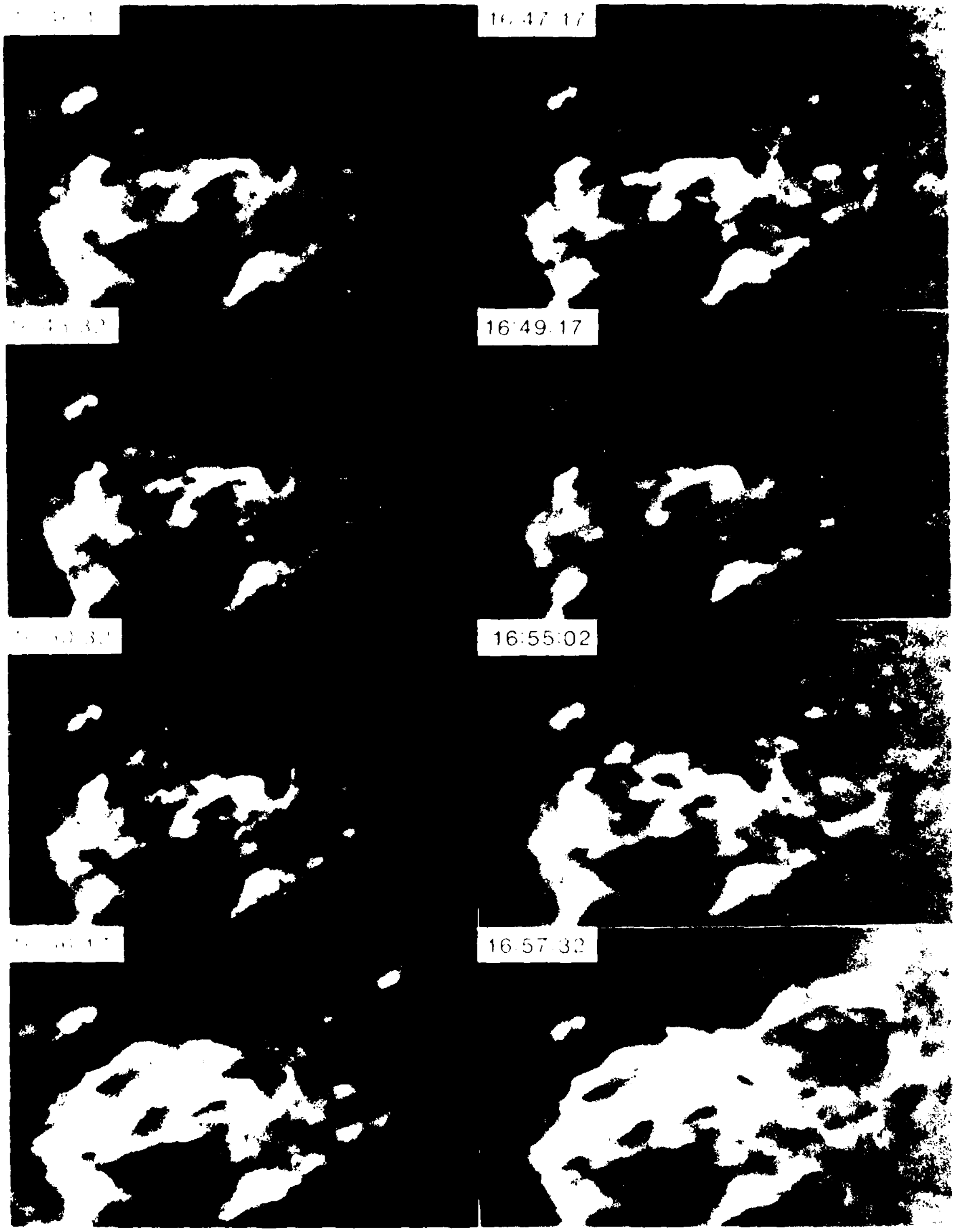


FIGURE 2

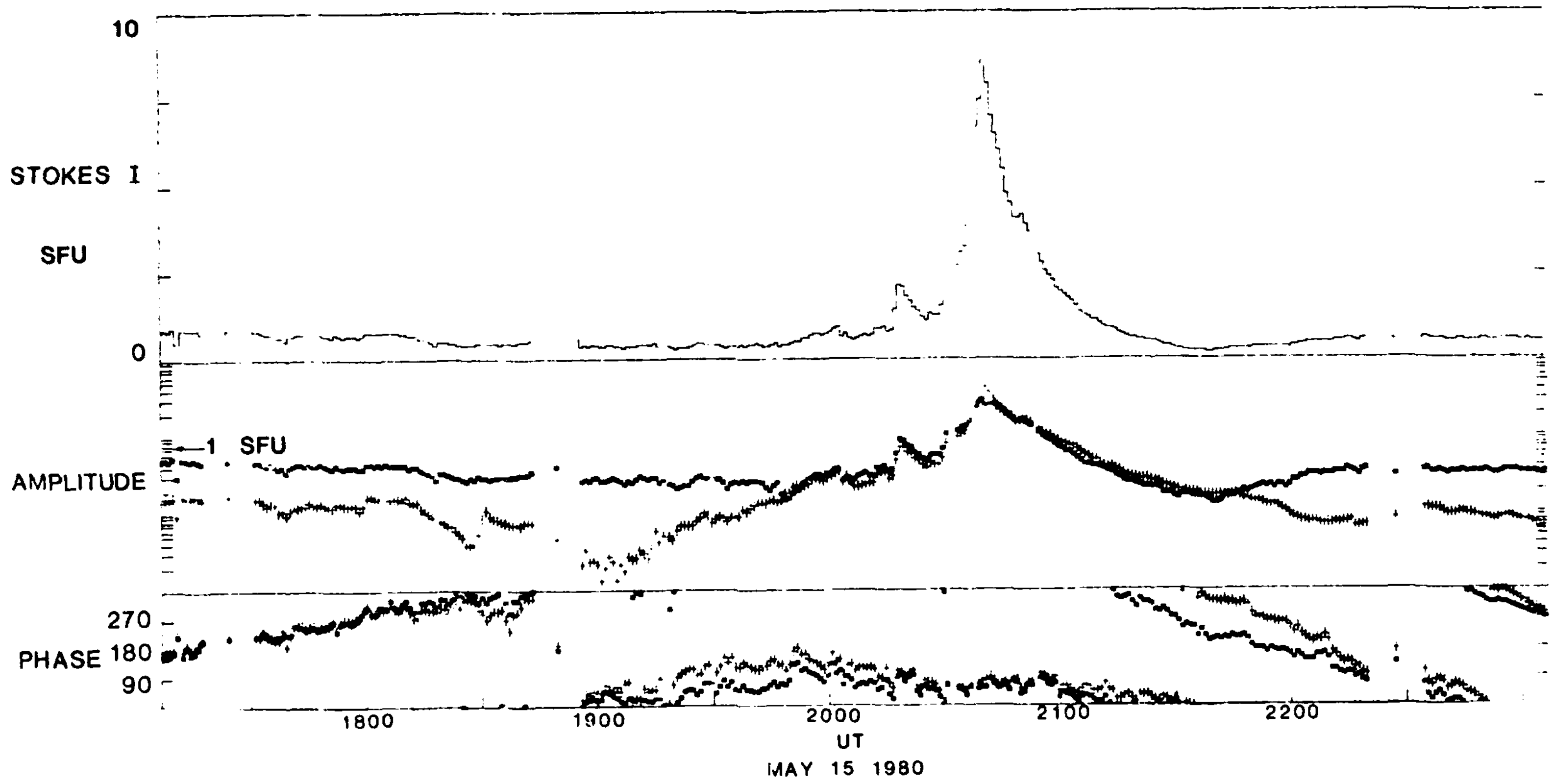

10
STOKES I
SFU
0
1 SFU
AMPLITUDE
270
PHASE 180
90
1800
1900
2000
2100
2200
UT
MAY 15 1980

FIGURE 3

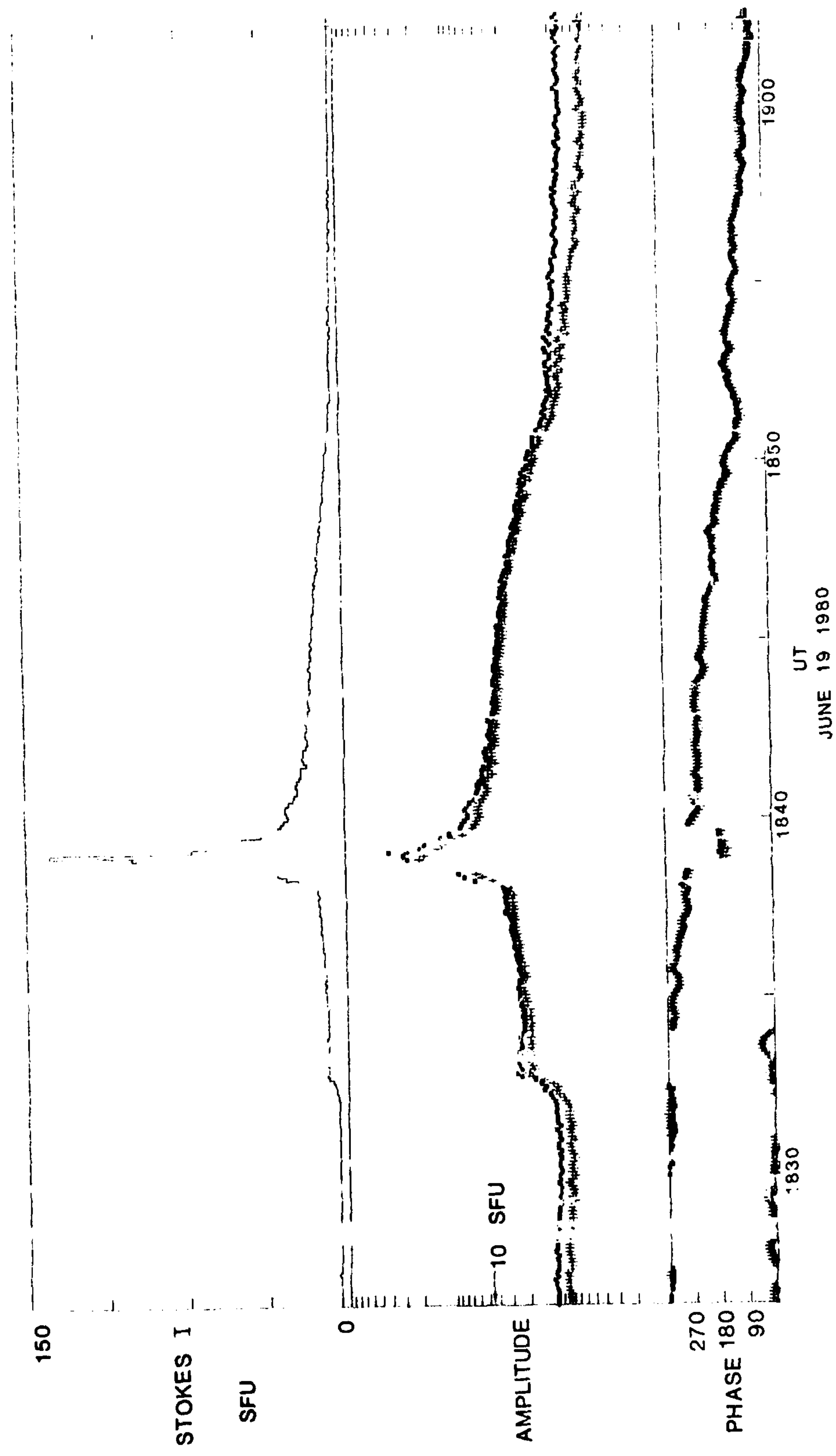

150
STOKES I
SFU
0
AMPLITUDE
10 SFU
270
180
90
PHASE
1830
1840
1850
1900
UT
JUNE 19 1980

FIGURE 4

6-19-80

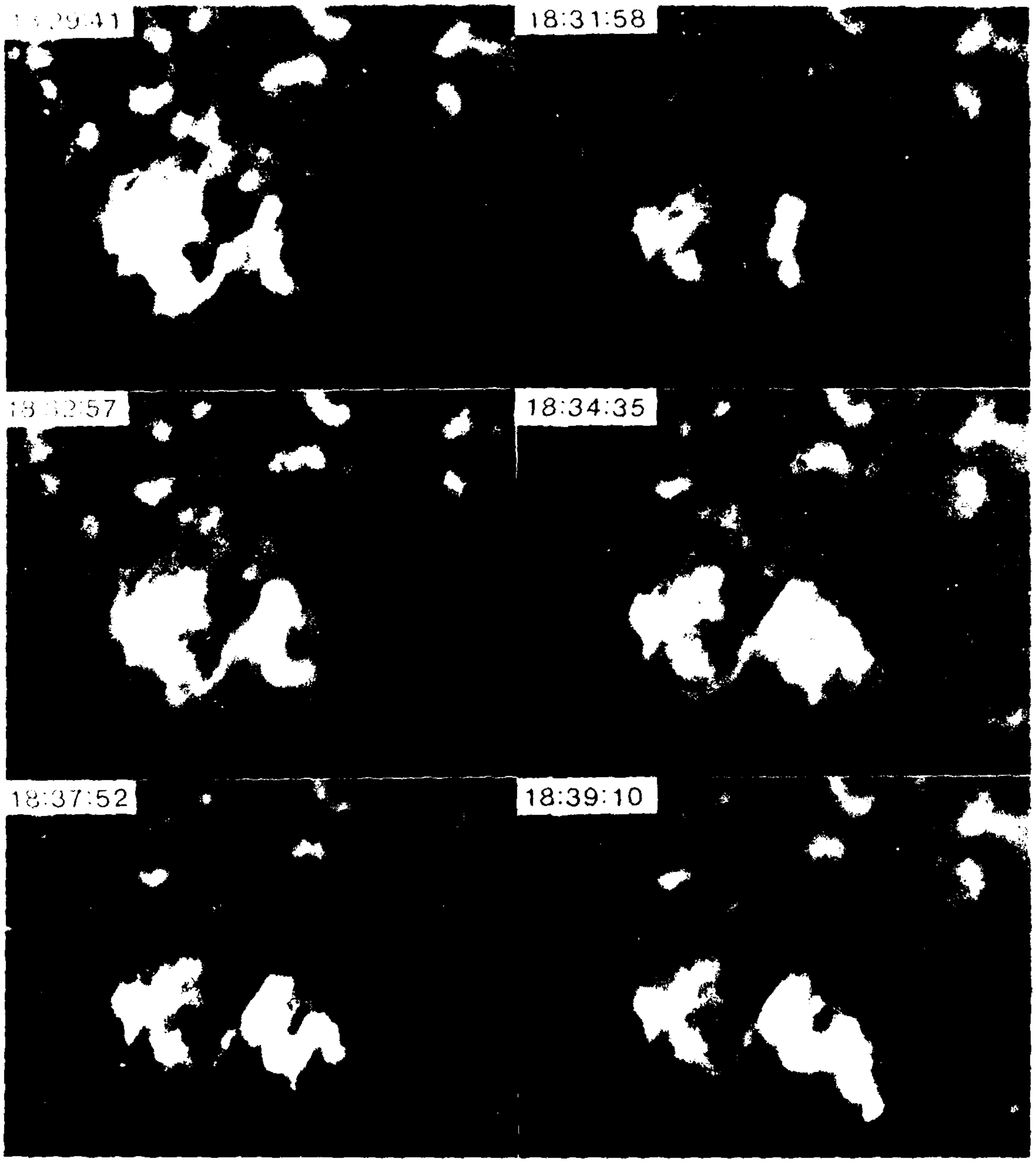


FIGURE 5

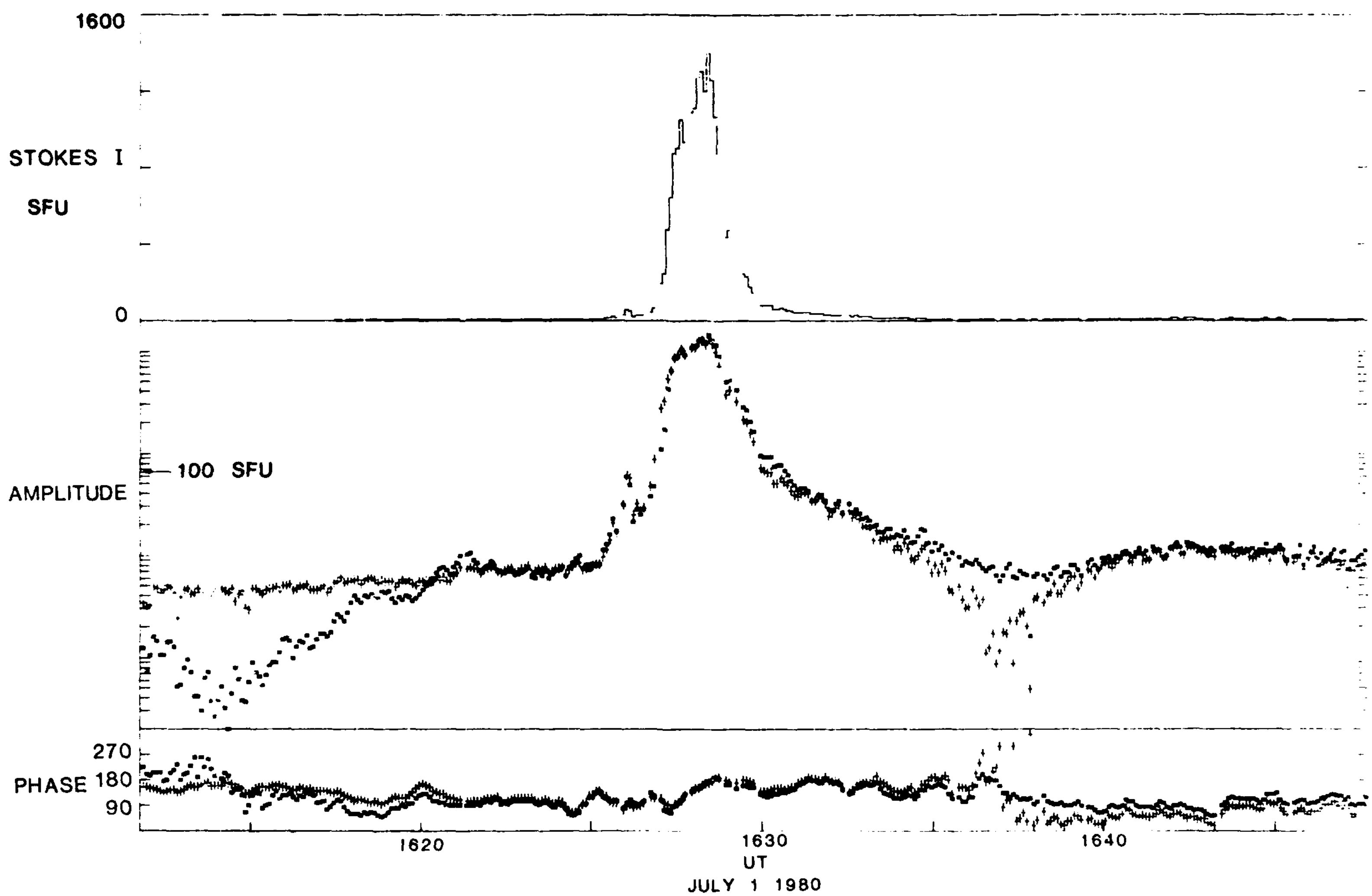

1600
STOKES I
SFU
0
AMPLITUDE
100 SFU
270
PHASE 180
90
1620
1630
UT
JULY 1 1980
1640

FIGURE 6

7-1-80

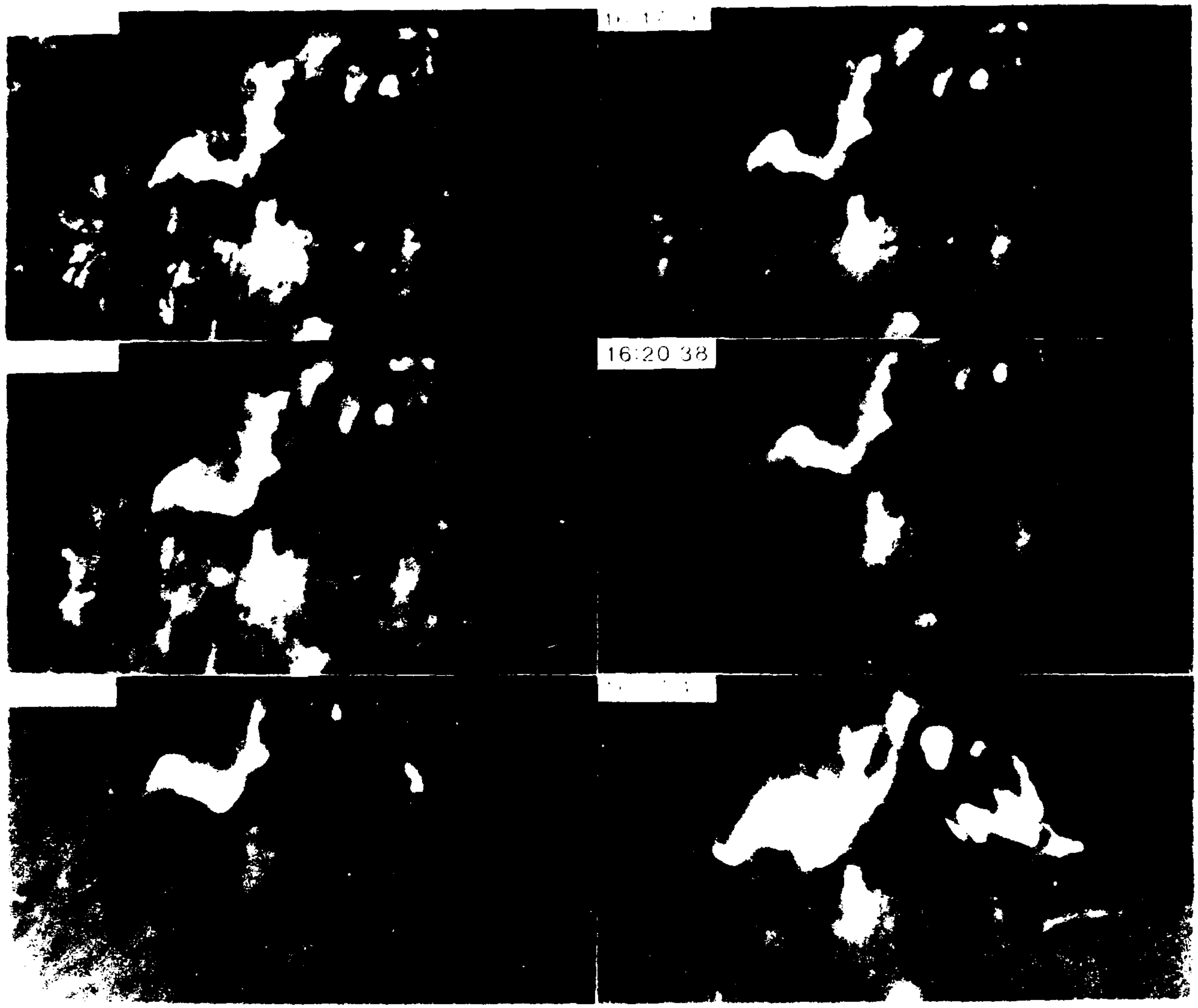


FIGURE 7

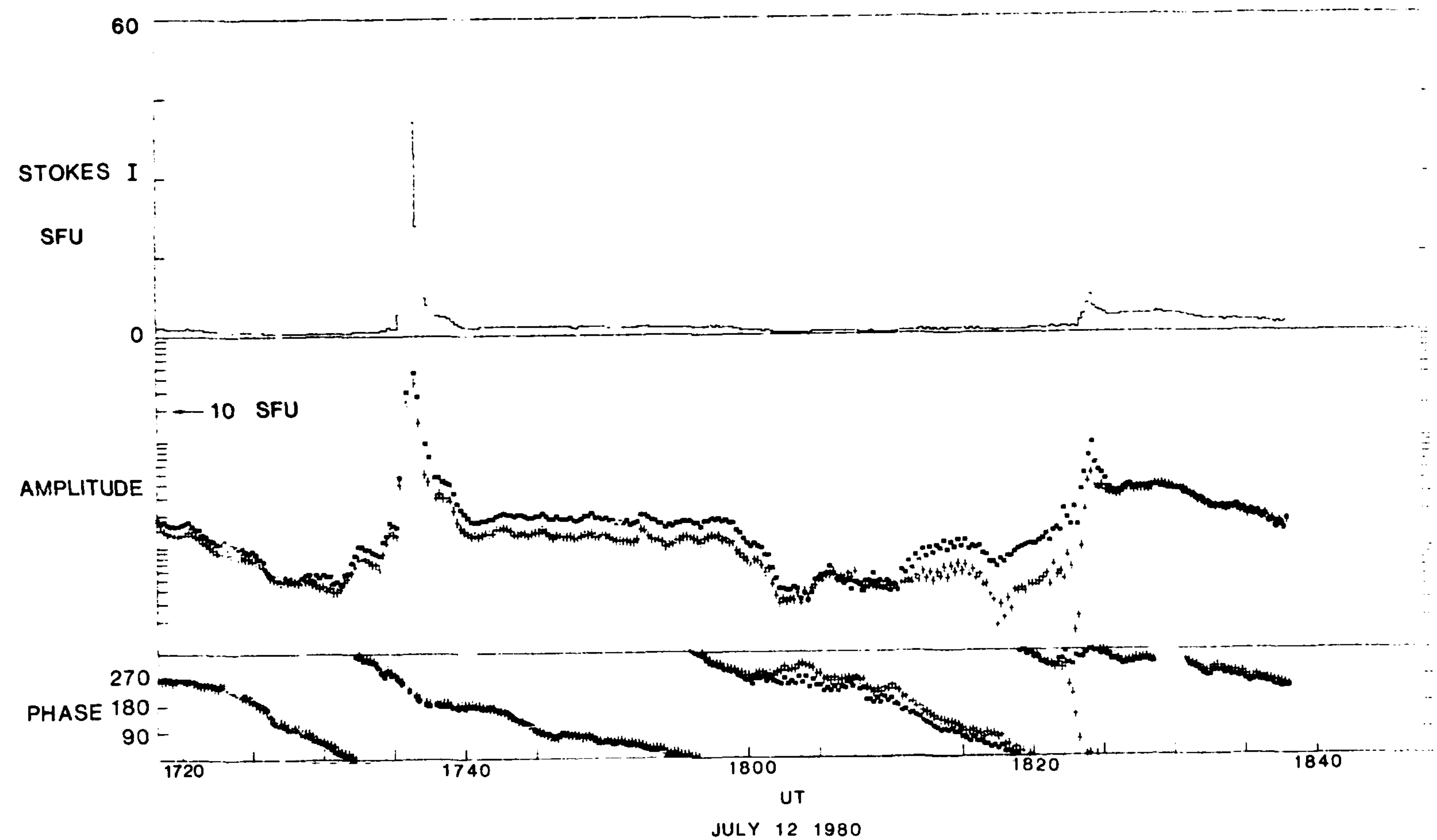

60
STOKES I
SFU
0
10 SFU
AMPLITUDE
270
PHASE 180
90
1720
1740
1800
1820
1840
UT
JULY 12 1980

FIGURE 8

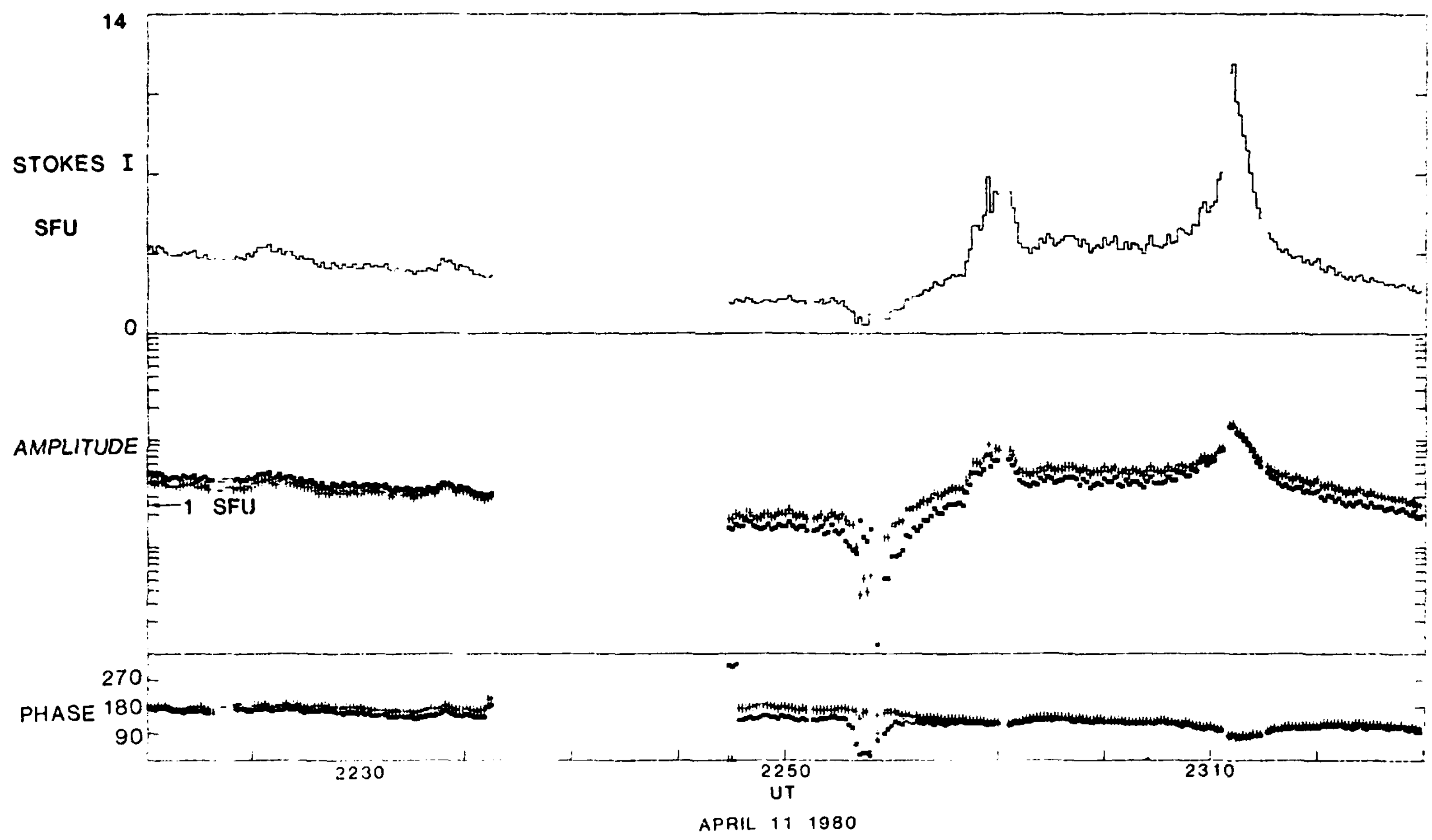

14
STOKES I
SFU
0
AMPLITUDE
1 SFU
270
PHASE 180
90
2230
2250
UT
2310
APRIL 11 1980

FIGURE 9

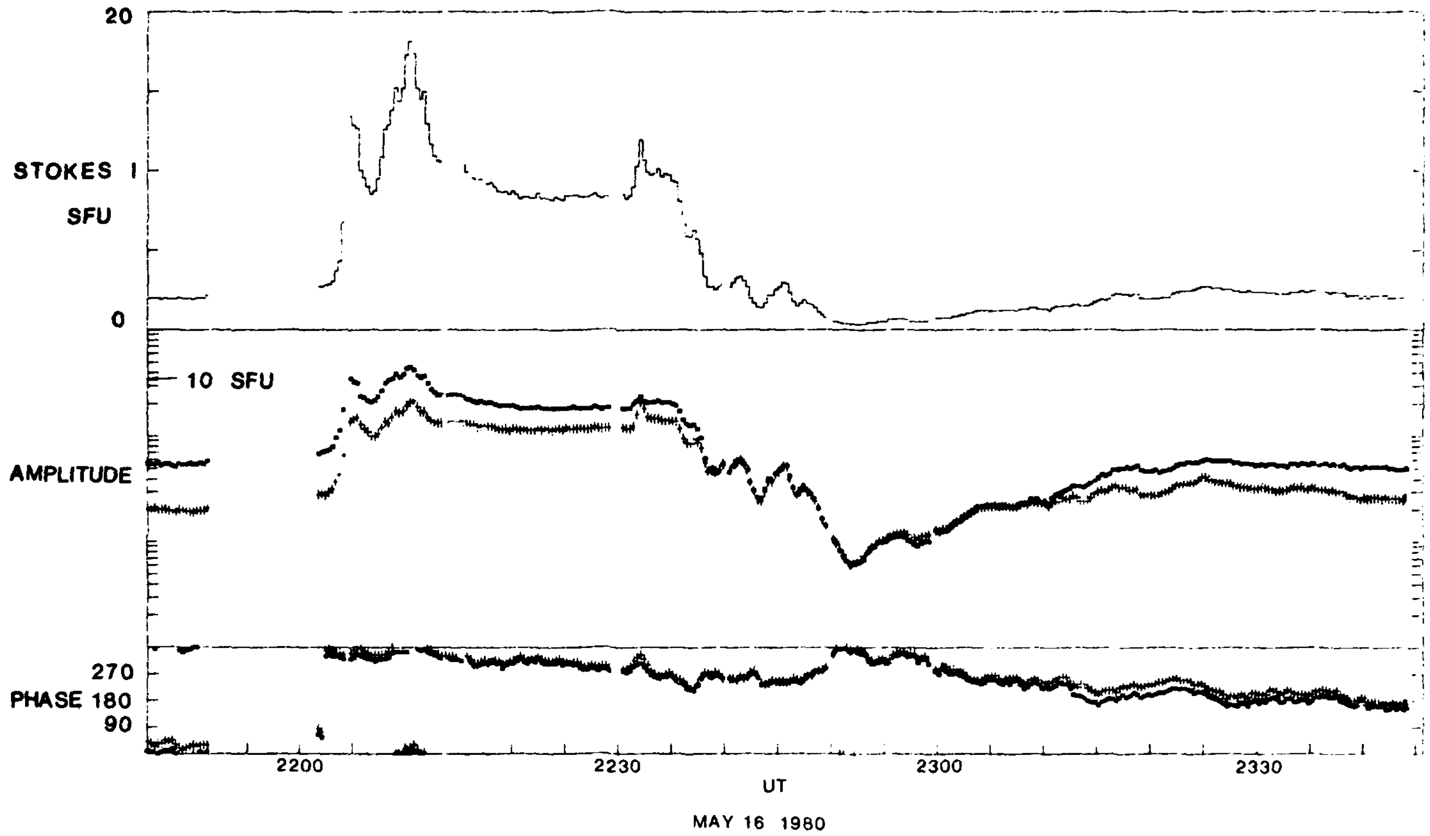

20
STOKES I
SFU
0
10 SFU
AMPLITUDE
270
PHASE 180
90
2200
2230
2300
2330
UT
MAY 16 1980

FIGURE 10

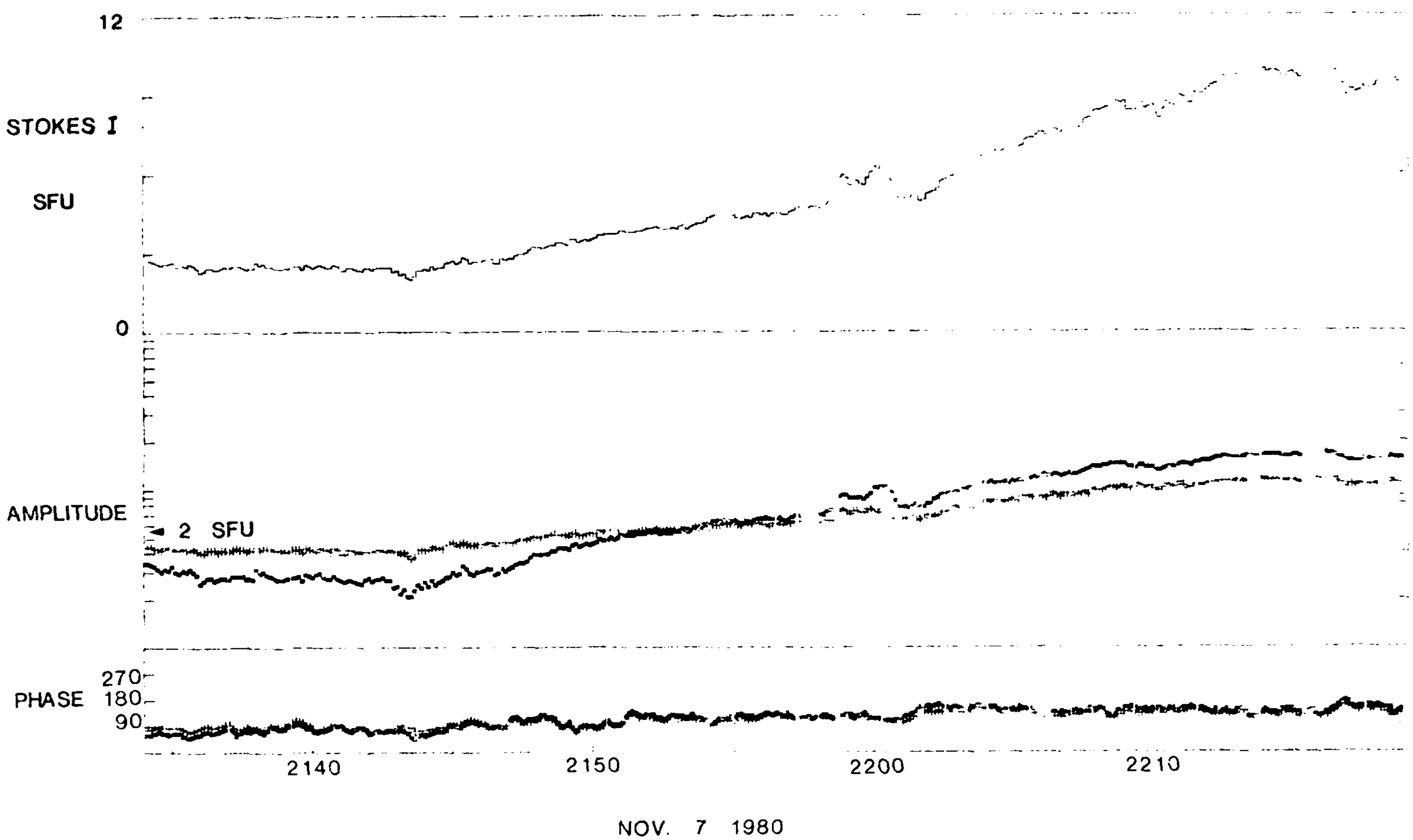

12
STOKES I
SFU
0
AMPLITUDE
2 SFU
PHASE
270
180
90
2140
2150
2200
2210
NOV. 7 1980

FIGURE 11

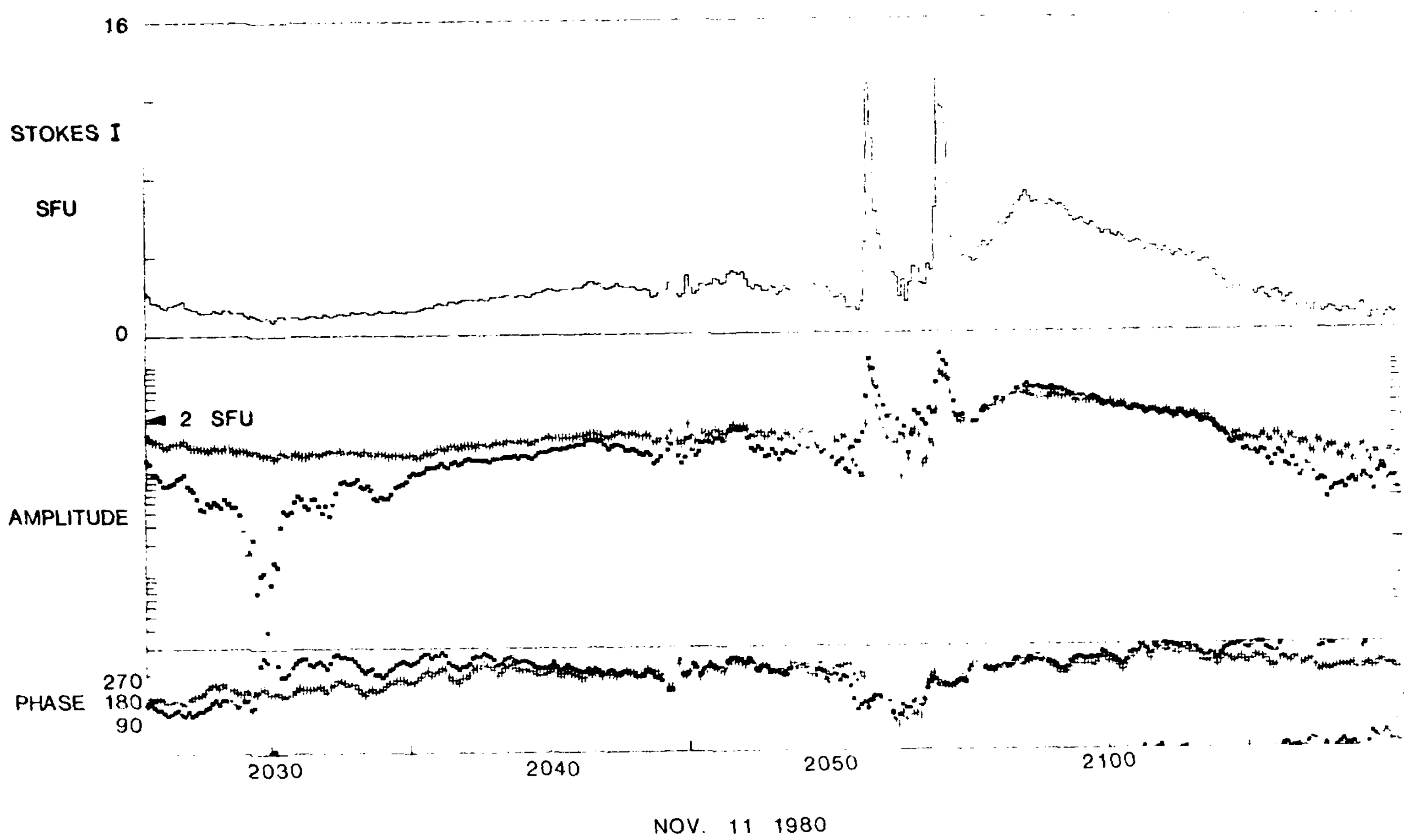

16
STOKES I
SFU
0
2 SFU
AMPLITUDE
270
PHASE 180
90
2030
2040
2050
2100
NOV. 11 1980

FIGURE 12

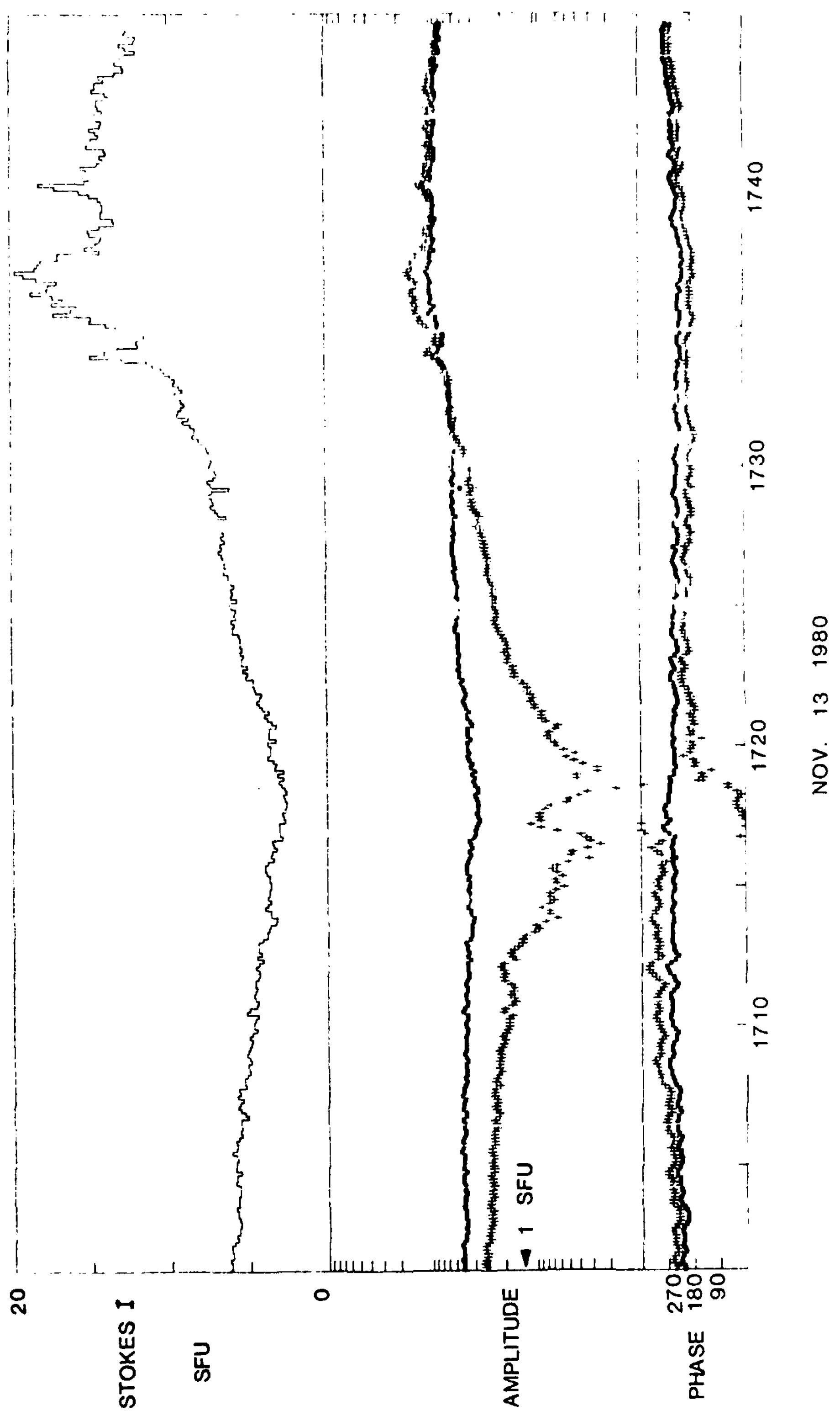
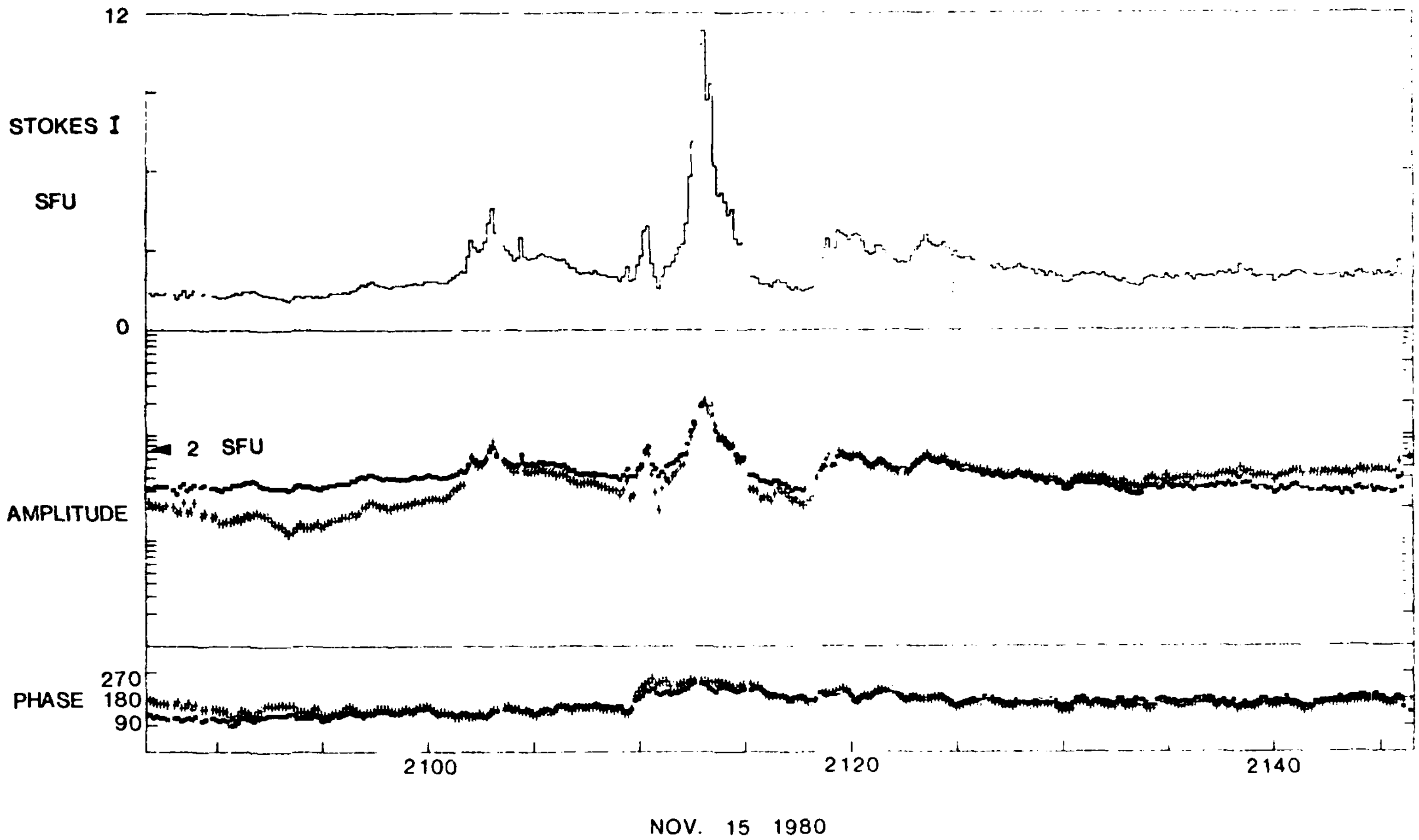

20
STOKES I
SFU
0
AMPLITUDE
1 SFU
PHASE
270
180
90
1710
1720
1730
1740
NOV. 13 1980

FIGURE 13



12
STOKES I
SFU
0
2 SFU
AMPLITUDE
270
PHASE 180
90
2100
2120
2140
NOV. 15 1980

FIGURE 14

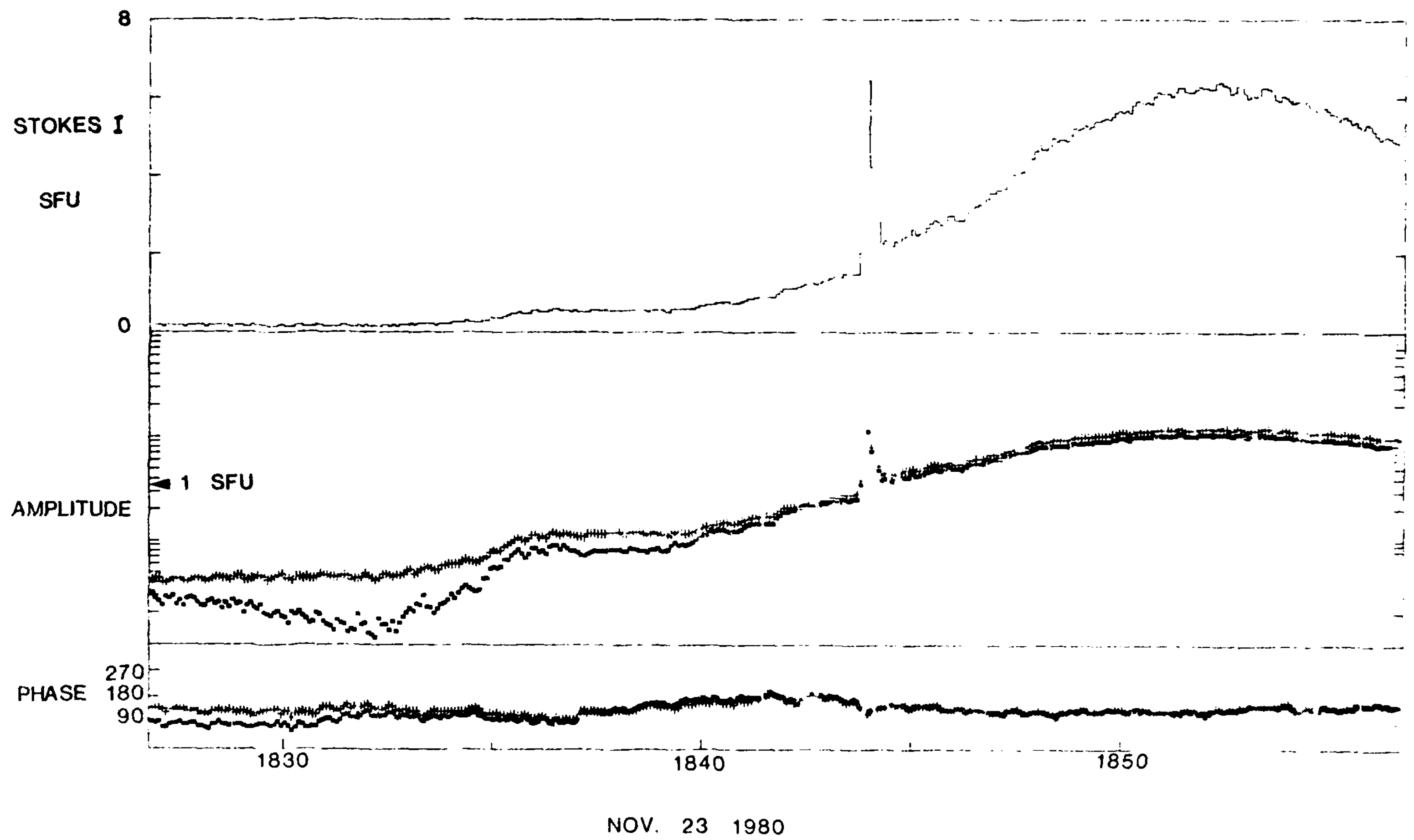

8
STOKES I
SFU
0
1 SFU
AMPLITUDE
270
PHASE 180
90
1830
1840
1850
NOV. 23 1980

FIGURE 15

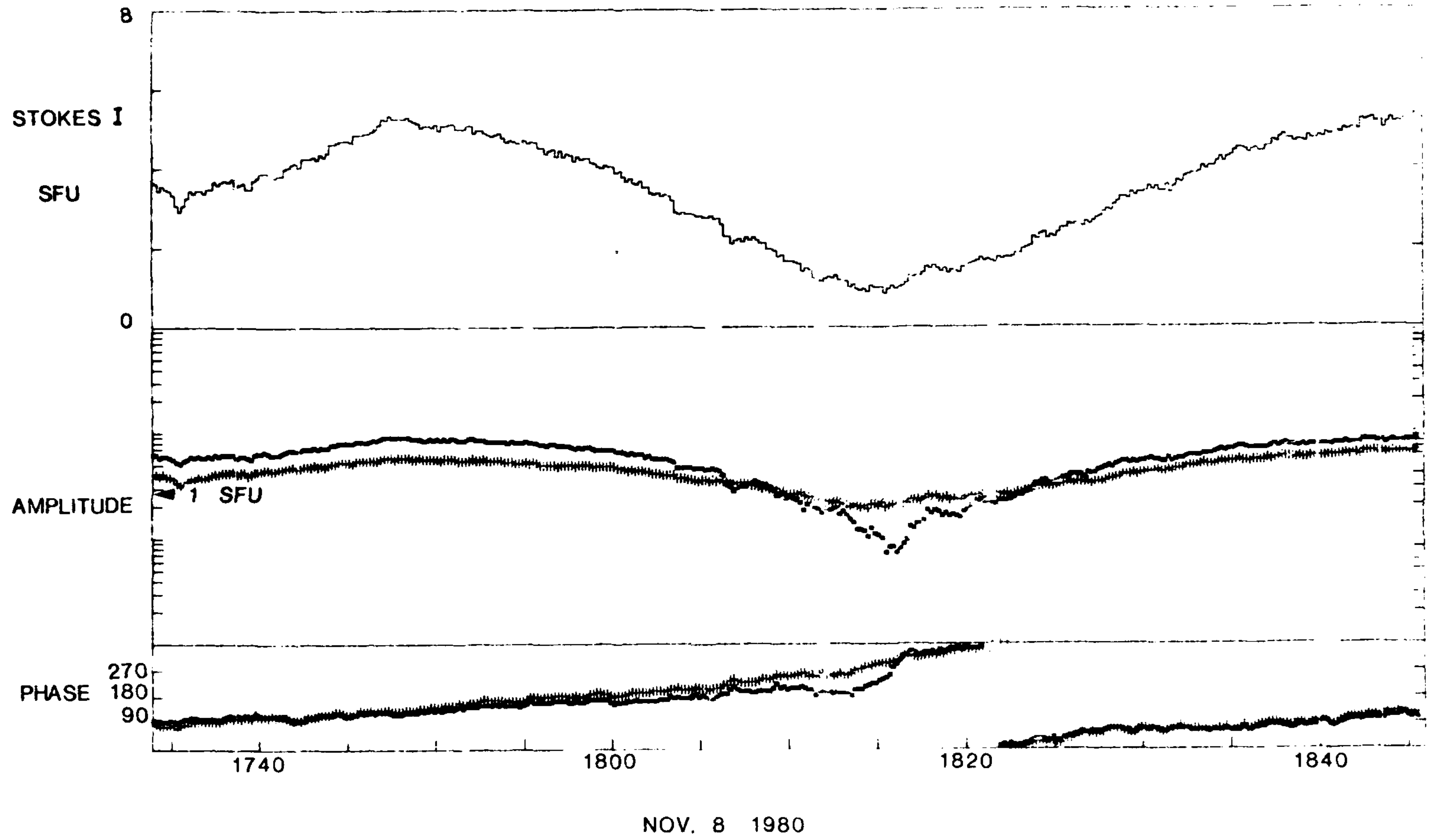

8
STOKES I
SFU
0
AMPLITUDE
1 SFU
PHASE
270
180
90
1740
1800
1820
1840
NOV. 8 1980

FIGURE 16